Seabed Variability and its Influence on Acoustic Prediction Uncertainty

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LONG-TERM GOALS

Assess and characterize uncertainty in the tactical naval environment. In littoral warfare, the seabed and its variability is a controlling factor in sonar system performance. To assess uncertainty in shelf environments, the two critical steps are:

(1) Characterize seafloor variability; and

(2) Assess the impact of seafloor variability on acoustic prediction uncertainty.

OBJECTIVES

1) Determine the uncertainty in the geoacoustic properties of the seafloor by assessing how natural variability in environmental parameters drive the seabed predictive model *2DSedFlux*. Parameters include variations in ocean climate, sediment supply and sea level. Of interest is how this variability couples with, or is independent of, numerical uncertainty in predicting the properties of the seafloor.

2) Develop *2DSedFlux* realizations in areas of interest to the seafloor geoacoustic team. *SedFlux* realizations provide data for seismic-convolution experiments, inverse experiments, propagation experiments and reverberation experiments. *SedFlux* simulations provide information on seafloor layering (position of layering, bed attributes: grain size, bulk density, porosity, permeability).

APPROACH

1) Characterize the variability of the environmental forces controlling the seabed at selected sites (New Jersey margin, Malta Plateau).

2) Conduct *SedFlux* realizations of seafloor attributes to capture the natural variability of modern-day climatology, and under climate change scenarios (wetter, drier, hotter, colder).

3) Provide geoacoustic modeling team *SedFlux* realizations to characterize the New Jersey margin.

4) Conduct *SedFlux* experiments to determine the impact of single events (e.g. large 100 y flood) on seafloor characteristics. Determine the magnitude of the change in the seafloor character, and provide this information as a probability density function.

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WORK COMPLETED

Wrapped up the project including final report and final publications (Jenkins, 2005; Kraft, et al., in press; Overeem, et al., 2005a; 2005b)

RESULTS

1) "Expert system" to retrieve boundary conditions on a global scale

Seabed modeling of the New Jersey Margin and the Malta Plateau allowed us to develop an expert system to mine the following databases: 1) global topography (e.g. SRTM), 2) global bathymetry, 3) global climate (e.g. NCEP Reanalysis), 4) ocean climatology (e.g. *WaveWatch III*). River basins change geometry over geological time under the influence of sea level that can expose the shelf and translate the coastline. The expert system combines topography and bathymetry and creates a geo-referenced Digital Elevation Model. With information on sea level fluctuations, the system determines changes in shelf morphology and coastline position. The expert system also derives: 1) paleo climate conditions from the Community Climate System Model (*CCSM*) run on selected time periods, 2) paleo ice sheet extent using output from glaciological models, and 3) paleo storm climate reconstructed from state-of-the-art proxies (e.g. dust records). Field observations (e.g. *dbSeabed*, paleobathymetry from seismic surveys, age information from core data) are then used to constrain *SedFlux* simulations.

2) Seafloor property prediction

During the Uncertainty DRI, the model *SedFlu*x was upgraded to: 1) be more computationally efficient using event-based discharge routines to better characterize the flux of sediment from land to sea, and its reworking through ocean storms, 2) ingest wave-climate statistics, 3) produce near-shore coastal-barrier, 4) erode the seafloor in shallow water, 5) winnow fine sediment under wave-orbital shear to form sediment lags on the seafloor, and transport fine material off of continental shelves, and 6) generate volume fractions of grain size classes, for acoustic Biot or Bingham phenomenological models.

3) Simulated seafloor off of New Jersey and the Malta Plateau

2DSedFlux records the thickness of the deposited sediment and its grain size properties, and then tracks the time-varying properties permeability, porosity and bulk density, along a spatially averaged 'corridor' normal to the shore. For the New Jersey Margin, shallow shelf stratigraphy was simulated from the coastline to a water depth of 150 m, for the last 40 Ky, at a resolution of 100 m horizontal and 10 cm vertical cells. The shelf stratigraphy of the Malta Plateau was simulated from the coastline to a 600 m water depth, for 1 My, at a resolution of 100 m horizontal and 20 cm vertical cells. Realizations are available to the Uncertainty DRI community: ftp://instaar.colorado.edu/pub/fromIrina/SEABED/. Other Seabed DRI investigators then generated the acoustic properties of the simulated seafloor using the Buckingham or Biot phenomological models for comparison with field observations (Pratson at Duke, Kraft and Mayer at UNH, Holland at Penn State).

4) Uncertainty associated with geological boundary conditions

Two attributes were used to quantify uncertainty in environmental parameters and their impact on simulated sea floor properties. The first, the *geometric attribute* (TH), characterizes departures in the thickness distribution of the simulated deposits. A second, *the grain size attribute* (GSD)*,* quantifies departures in the predicted grain size in the uppermost seafloor layer. The range in the uncertainty of the different boundary conditions is estimated to be about 20%. Uncertainties in environmental estimates like drainage area and elevation, temperature and precipitation, influence a river's sediment supply to its margin. Uncertainty in elevation is the most sensitive factor when modeling formerly glaciated margins, where uncertainties relate to the thickness of the former ice sheet that covered the drainage basin. The possible range in drainage area has less impact on seafloor predictions. Paleo storm climatology is another sensitive parameter. Uncertainty increases as one simulates further back in geologic time as the uncertainties in environmental input compound. Thus *SedFlux* simulations show increasing uncertainty with depth below the seafloor. Accuracy of paleo environmental conditions is necessary in reducing uncertainty in stratigraphic predictions. This suggests that *2DSedFlux* will better predict the acoustic properties of sediments that have been deposited over the past millennia in regions of high sediment accumulation (e.g., offshore of major rivers).

4) ***SedFlux*** **predictions against first-order field measurements**

SedFlux simulations were tested against New Jersey data (measurements in the upper 10 cm of the seafloor via grain size analysis of grab samples, *in-situ* UNH velocity probe measurements using geoacoustic inversion). The thickness and sedimentary facies simulated by *SedFlux* are comparable to sedimentary units identified by seismic profiles above a well-studied "R" reflector . The simulation results show similar grain size variability with water depth as found in observations. Predictions were substantively improved with the new shelf storm module and wave climate data. The ranges in deposited thickness of the sediment are well within the lateral variability as mapped in 3D from the seismic data. A second test was the quantitative comparison of *SedFlux* predictions with observed grain size data (654 seafloor samples from the New Jersey shelf between 40 and 160 m water depth). *SedFlux* simulations show a narrower range of sea floor grain size than the sea floor data set. This is explained by the exceptionally coarseness in the grab sample data, and the lack of gravel used as input to *SedFlux* simulation. In sensitivity experiments, when a coarser initial grain size distribution was used, *SedFlux* predicted the grain size in the range of the observed values, although with a slight over-prediction of fine sediment at the seafloor. Shelf stratigraphic models need to do a better job in simulating seafloor sediment lags.

5) **Tested the** ***SedFlux*** **predictions against geoacoustic measurements**

SedFlux grain-size predictions were combined with two acoustic models (Buckingham or Biot phenomological models) to estimate sound speed with distance across the shelf and with depth below the seabed interface. Acoustic model predictions (Pratson at Duke U., Kraft and Mayer at UNH, Holland at Penn State) were compared with two independent sets of data: (1) seafloor sound speeds obtained through direct measurement using in-situ compressional-wave probes and (2) sound speed as a function of depth obtained through inversion of seabed reflection measurements. These acoustic model predictions produced the same trends decreasing sound speeds with increasing water depth as are seen in the measured data. Predicted grain sizes are finer (~ 1 to 2 ϕ), which the Buckingham model translates into a sound speed difference of 120 m/s or 6.9% of the mean sound speed of 1726 m/s. Near-surface *SedFlux-Acoustic* predictions are most successful near the seafloor, less so with deeper sub bottom predictions. Sound speeds obtained by inversion methods depart from the predicted sound speeds by hundreds of meters per second, and in a number of cases exhibit distinctly different trends. Uncertainty increases in depth below the seafloor with the paleo estimates used in the model.

Some of the uncertainty (±50-100 m/s) comes from the relationship between mean grain size and sound speed. Both the Buckingham and EDFM models yield reasonable predictions for sound speed as a function of grain size, but both have errors and numerous free parameters. These models also differ in their theoretical formulation and which is the more appropriate to use is presently the subject of considerable debate.

IMPACT/APPLICATIONS

The range in the geological boundary conditions for *SedFlux* modeling increases in simulations across long geological periods and may lead to significant uncertainties in sub-seafloor realizations. The uncertainties can be quantified. Ingestion of field observations (even if very limited in scope) can constrain *SedFlux* simulations (e.g. the range in observed seafloor grain size classes or the age model of the shallow sequences based on seismic data or cores). An expert system allows for better estimates of sensitivity and uncertainty in model predictions.

Some seafloor features are inherently a result of processes acting in three dimensions and certain features (buried channels) are not efficiently captured in 2D modeling. Cores collected in these spatially variable features are not be adequately modeled. This complicates one-to-one comparison and validation of model results to field data. Some continental margins can be considered 2D environments (e.g. sedimentation-dominated Eel Margin). Developing and employing a *3DSedFlux* would address many of these concerns.

Testing *SedFlux* in different environments allows model refinement to more readily handle earth's diversity. The New Jersey shelf was not an ideal place to exercise *SedFlux*, as the present of a paleo ice sheet adds complexities that are not common to non-glaciated margins. Further, substantial along shelf variability underscores need for 3D modeling efforts. Improvements to the modeling approach could be made as follows:

1) *HydroTrend*, a model separate from *SedFlux*, needs improvements in its ability to predict the grain size being released from a melting ice sheet;

(2) *SedFlux* does not include a biological component that could produce shelly material and with reworking shell hash, and could account for the under-prediction in terms of grain size;

(3) *SedFlux* does not yet include a bedform generating module, and this may impact the sound speed in sandy layers;

(4) New Jersey margin has many geological features that have manifestations in 3 dimensions (buried channels, large-scale bed-features), limiting the application of a strictly 2D modeling approach.

TRANSITIONS

ExxonMobil now uses *SedFlux* code in both reservoir characterization and as an exploration tool. Nine oceanographic institutes now employ scientists that are using *SedFlux*. The *SedFlux* modular architecture is used as a proto-type example in National Science Foundations efforts to develop a Community Surface Dynamic Modeling System.

RELATED PROJECTS

ONR GeoClutter: http://instaar.colorado.edu/deltaforce/projects/geo_clutter.html

ONR EuroSTRATAFORM: http://instaar.colorado.edu/deltaforce/projects/euro_strataform.html

PUBLICATIONS

Jenkins, C.J. 2005. Quantifying the Uncertainty in Marine Substrate Mappings. Continental Shelf Res. [submitted, refereed]

Kraft, B.J., Overeem, I., Holland, C.W., Pratson, L.F., Syvitski, J.P.M., Mayer, L.A., 2005, Stratigraphic Model Predictions of Geoacoustic Properties, Journal of Ocean Engineering. [in press, refereed]

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Overeem, I., Syvitski, J.P.M., Hutton, E.W.H., 2005b. Three-dimensional numerical modeling of deltas. SEPM Spec Issue 'Deltas :systems and processes'. [in press, refereed]